

# Study on the use of antiwash high performance concrete for rehabilitating the hydraulic structure submerged in water

Nguyen Viet Duc<sup>1</sup>

**Abstract:** Antiwash high performance concrete (AHPC) is a specialized type of concrete used for construction projects where concrete needs to be placed below the waterline. With the aim to extend the service life of the hydraulic structures under water, this paper attempts to study on AHPC and its usage for rehabilitating the structure submerged in water. To do so, four AHPC mixtures have been involved in the experiment, in which superplasticizer dosages varied from 1% to 2% in conjunction with a specialized anti-washout admixture. Besides, a particular AHPC mixture would be used for repairing the structure by underwater concreting. The experimental results have shown that at fresh state the higher superplasticizer dosage, the higher slump flow of the AHPC mixtures, and the higher mixture mass loss inside the water. Meanwhile, at hardened state the higher superplasticizer dosage, the higher compressive strength gains. The single AHPC, which achieved slump flow of 20 cm and strength class of 50MPa, was chosen for successfully rehabilitating the structure submerged in water by mean of tremie method. The proposed future work could involve the study on mechanical performance of the concerned structure after rehabilitation.

**Keywords:** Antiwash high performance concrete, hydraulic structure, underwater concreting, anti-washout admixture, superplasticizer.

## 1. Introduction

Vietnam has 3,450 rivers and streams with a length of 10 km or more. These rivers and streams are located in 108 river basins distributed and spread across the country with a total basin area of about 1,168,420 km<sup>2</sup>, of which 837,430 km<sup>2</sup> (around 71.7%) are located abroad, only 330,990 km<sup>2</sup> (i.e. 28.3%) of the basin area is located within the country. Of the total 108 river basins, there are 33 large, inter-provincial river basins, with 3,140 rivers (accounting for 91% of the total number of rivers in the country), the total basin area within our country is about 306.44 thousand km<sup>2</sup>, equal to 92.6% of the country's land area. Among them, there are 13 large and important river basins, including: the Red - Thai Binh, Bang Giang - Ky Cung, Ma, Ca, Huong, Vu Gia - Thu Bon, Tra Khuc, Kon - Ha Thanh, Ba, Se San, Sre Pok, Dong Nai, and Mekong River basins. The large rivers originate from alien countries and flow through Vietnam to the sea, such as the Red, Ca, and Mekong rivers, or have a section in the middle that flows through Laos, such as the Ma River. In particular, the Ky Cung and Bang Giang rivers originate in Vietnam, but flow into China (Nguyen, 2022).

In addition, Vietnam is a coastal country located on the West coast of the East Sea, with very important geopolitics and geo-economics that a few countries in the world have. With a coastline of over 3,260km stretching from North to South, from Mong Cai province in the North to Ha Tien province in the

Southwest (not including the coastline of the islands, ranked 27<sup>th</sup> out of 157 coastal countries, island nations and territories in the world). With over 3,000 large and small islands, including the two archipelagos of Hoang Sa and Truong Sa, Vietnam is considered one of the countries with great potential and advantages in marine and island resources (Nguyen 2023).

The coasts, rivers, streams and lakes of Vietnam are places with very beautiful landscapes, but they are not convenient locations for the construction works. However, in order to develop the socio-economy and transportation, the country still depends on many types of infrastructure in places with such water environments, such as harbors, bridges and dams, part of which have been built under water. In addition, some sewers, tunnels, and marine projects must also be constructed underwater. Or it can be said that the demand for construction projects related to the water environment such as hydraulic and marine projects, bridges, etc., is very large in Vietnam. Currently, concrete materials and reinforced concrete structures are widely used for these construction items (Ngo, 2020).

In general, concrete and reinforced concrete structures working in water-submerged environments (seas, rivers, ponds, lakes) are often subject to the impact of intense aggressive agents due to the penetration of water and its harmful components, as well as other mechanical and physical impacts. Working in a water environment combined with the erratic climate changes in recent years has led to the service life of these structures being much lower than the original design and many structures have shown many failures (surface pitting, concrete erosion, peeling of the protective layer of reinforcement, etc.) very early. Hence, they need to be repaired to enhance the service life (Nguyen & Vu, 2021).

<sup>1</sup>Division of Construction Materials, Faculty of Civil Engineering, Thuyloi University

Received 25<sup>th</sup> Apr. 2025

Accepted 7<sup>th</sup> Oct. 2025

Publication date 31<sup>st</sup> Dec. 2025

With the aim to improve the lifespan of the hydraulic structures under water, this paper intends to study on antiwash high performance concrete (AHPC) and its usage for rehabilitating the structure submerged in water. The underwater concreting is carried out particularly by mean of the tremie method (Pham, 2007).

**2. Materials and methods:**

The materials used for preparation of AHPC are presented as follows:

**2.1. Cement and silica fume**

Blended Portland cement PCB40 with commercial brand Long Son, which is conforming to the Vietnamese standard TCVN 6260:2020, is used in this study. Physical and mechanical characteristic of cement are given in Table 1.

In addition, silica fume with commercial brand Elkem Microsilica® 940, which is conforming to the Vietnamese standard TCVN 8827:2011, is used as supplementary cementitious material in combination with cement in AHPC. Silica fume has a very small particle size from 0.01 µm to 2 µm, average diameter of 1.5µm, i.e. it can be 100 times smaller than cement particles. Besides, the SiO<sub>2</sub> content accounts for 85% to 98% by weight. Physical and chemical characteristic of silica fume are included in Table 2.

**Table 1.** Physical and mechanical characteristic of cement

Parameters	Units	Test results
Specific density	g/cm <sup>3</sup>	3.11
Bulk density	g/cm <sup>3</sup>	1.32
Blaine fineness	cm <sup>2</sup> /g	3730
Consistency	%	28.5
Initial setting time	min.	155
Final setting time	min.	230
Soundness of cement	mm	1.0
3 days compressive strength	N/mm <sup>2</sup>	25.1
28 days compressive strength	N/mm <sup>2</sup>	46.5

**Table 2.** Physical and chemical characteristic of silica fume

Parameters	Units	Test results
Specific density	g/cm <sup>3</sup>	2.11
Bulk density	g/cm <sup>3</sup>	0.925
Loss on ignition	%	4.2
Content of SiO <sub>2</sub>	%	93.5
Content of Al <sub>2</sub> O <sub>3</sub>	%	0.92
Content of Fe <sub>2</sub> O <sub>3</sub>	%	0.52
Content of SO <sub>3</sub>	%	0.63
Content of CaO	%	1.57

**2.2. Fine aggregate**

This study promotes the implement of crushed stone sand as the replacement of costly natural river sand. Sand from Kien Khe - Ha Nam Province is opted for proportioning SCM. The characteristic conforming

TCVN 7572:2006 is given in Table 3. Besides, in order to obtain grading of aggregates, sieve analysis is also carried out, and the results are provided in Table 4.

**Table 3.** Characteristic of crushed stone sand

Parameters	Units	Test results
Specific density	g/cm <sup>3</sup>	2.67
Bulk density	g/cm <sup>3</sup>	1.65
Porosity	%	38.2
Moisture content	%	1.0
Clay, silt and dust content	%	0.5
Fineness modulus	-	2.57

**Table 4.** Gradation of crushed stone sand by sieve analysis

Sieve size (mm)	Cumulative percent
5	0.0
2.5	9.0
1.25	23.5
0.63	46.3
0.315	84.0
0.14	94.5
Pan	100

**2.3. Chemical admixtures and water**

The anti-washout admixture used in this study is Sika® UCS. It is a white powder, as shown in Figure 1, which is formulated to increase the cohesion of concrete, enabling significant reductions in both binder washouts in underwater concrete and static segregation for piled concrete in absorbent ground.



**Figure 1.** Anti-washout admixture used in this study

According to the supplier, Sika® UCS should be added in a range of 2-3 kg per a cubic meter of concrete. Indeed, this admixture has the following

characteristics and should be used in combination with a superplasticizer:

- Strong increase in cohesion;
- Extended workability;
- Superior anti-washout properties;
- Provides improved integrity of concrete placed underwater;
- Reduced segregation and moisture loss to ground in concrete piles;
- Less segregation and bleed;
- Packaged in water soluble bags for easy dispensing.

In the meantime, superplasticizer used in this study is a high-range water reducer admixture, which is a third generation polycarboxylate superplasticizer with a brand VMAT-PC01. Water used for mix proportion is tap water at Hanoi area. Characteristic of superplasticizer and water is shown in Table 5.

**Table 5.** Characteristic of superplasticizer and water

Parameter	Units	Superplasticizer	Water
Specific density	g/cm <sup>3</sup>	1.075 ÷ 1.095	1.0
pH value	-	4 ÷ 6	7
Solid content	%	25.6	-

**Table 6.** Mix proportion of SCM

	PCB40	Silica fume	Sand	Anti-washout admixture	Water	SP	SP/PCB40
	kg	kg	kg	kg	L	kg	-
M1	450	45	1605	2.7	185	4.5	1.0%
M2	450	45	1605	2.7	185	6.3	1.4%
M3	450	45	1605	2.7	185	7.2	1.6%
M4	450	45	1605	2.7	185	9.0	2.0%

### 2.5. Experimental test

After a relevant mixing procedure, AHPC mixtures (M1, M2, M3, and M4) were tested at fresh state in order to define slump-flow value in accordance with the standard TCVN 9204:2012, as it is illustrated in Figure 2.



**Figure 2.** Slump-flow test on AHPC mixture at fresh state

### 2.4. Mix proportion of AHPC

In this study, AHPC mixture corresponding to strength class of 50MPa at the age of 28 days is designed. Besides, the mixture has to sound in case of underwater concreting, i.e. it has the highest anti-washout properties. Since there is no particular standard or guideline on mix design of AHPC, the authors have followed mix design recommendation of high performance self-compacting concrete (HPSCC) developed by professor Okamura, who was considered as the first person introduced HPSCC to the scientific society (Okamura & Ouchi, 2003). Besides, several guidelines on SCC from EFNARC have been taken into consideration [EFNARC, 2002, 2006]. The detailed mix design steps are described elsewhere in the published document (Ngo, 2020).

Some “trial-and-error” were involved into mix proportion of AHPC. Eventually, in total there are three mixes used in this study as it can be seen in Table 6. Among them, it is noteworthy that the difference in the mixtures is the superplasticizer dosage varying from 1.0% to 2.0% in comparison with the cement content, apart from the anti-washout admixture being kept permanent.

Regarding the anti-washout property of AHPC, it is determined by the mass loss once AHPC is placed into water. A certain amount of AHPC is poured into the net-like tool and then it is submerged into water. After a while, it is lifted out of water and weighted to determine how much mass of AHPC lost. This value would present the anti-washout property of AHPC.



**Figure 3.** Test of AHPC anti-washout property

Afterward, three prism specimens (40x40x160 mm<sup>3</sup>) for each mixture were prepared in order to determine compressive strength and flexural strength at 28 days, as it can be seen in Figure 4.



**Figure 4.** AHPC placement into mould 40\*40\*160 mm<sup>3</sup>

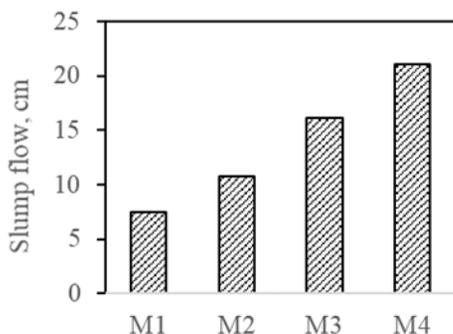
After casting AHPC mixture into the corresponding moulds, the specimens were kept in the laboratory for 24 hours, then they were removed from the moulds and cured under the standard condition (T=20±2°C; W>95%) up to the testing date.

### 3. Results and discussion:

#### 3.1. Fresh properties

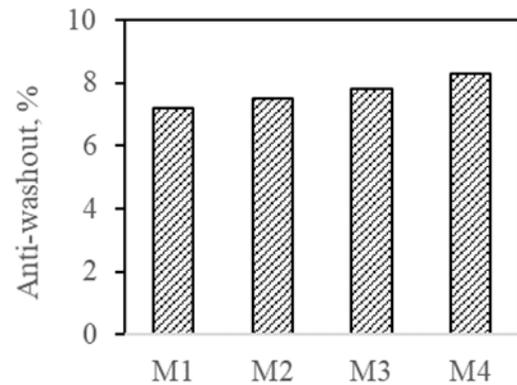
Slump flow of AHPC mixtures M1, M2, M3, and M4 corresponding to superplasticizer dosage of 1.0%, 1.4%, 1.6% and 2.0% respectively is shown in Figure 5. The slump flow magnitude varies from 7 cm to more than 20 cm. It can be observed that the higher superplasticizer dosage the higher slump flow of the mixtures i.e. the more workable mixture, as shown in Table 6 and Figure 5.

This outcome is evident that the role of superplasticizer has taken advantages, as same as it has been published in many publications before (Neville, 2002). Besides, it is also noteworthy that superplasticizer still works well in compatibility with the anti-washout admixture Sika® UCS. However, according to TCVN 9204:2012, the M4 mixture seems to be the only one suitable, as the slump flow excels 20 cm.



**Figure 5.** Slump flow of AHPC mixtures

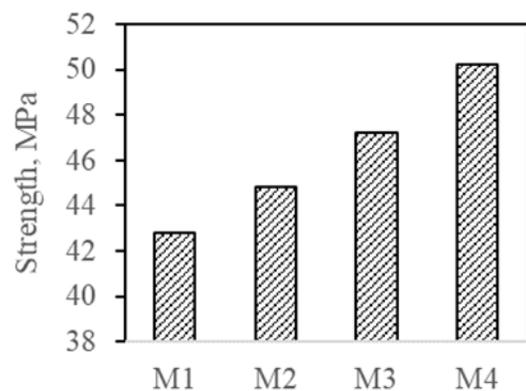
Regarding anti-washout property of the AHPC mixtures M1, M2, M3 and M4 inside the water, the result is demonstrated in Figure 6. It shows that the higher superplasticizer dosage the higher mass loss inside the water. However, the discrepancy of the magnitude among them is quite small about only 1%. The increase of mass loss inside the water can be explained due to the high flowability of mixture once the more superplasticizer content is added, as shown in Figure 5. It turns out that the more the mixture moves more i.e. high flowability, the more likely it is prone to bleeding (Vu, 2011). This is the main reason of mass loss inside the water.



**Figure 6.** Anti-washout of mixtures in water

#### 3.2. Hardened properties

Compressive strength of the AHPC M1, M2, M3 and M4 corresponding to superplasticizer dosage of 1.0%, 1.4%, 1.6% and 2.0% respectively is illustrated in Figure 7. It is seen that the higher superplasticizer dosage, the higher compressive strength gains. The similar result is obtained in case of flexural strength of the AHPC M1, M2, M3 and M4 corresponding to superplasticizer dosage of 1.0%, 1.4%, 1.6% and 2.0% respectively, which is shown in Figure 8. Since the designed strength class is 50MPa at the age of 28 days as mentioned before, the AHPC M4 is the only one complying the technical requirement.



**Figure 7.** Compressive strength of AHPCs

### 3.3. Underwater concreting for rehabilitation

Indeed, according to the fresh and hardened properties of the AHPCs used in this study, the M4, mix proportion of which is presented in Table 6, is appropriate to be used for underwater structure rehabilitation. In this study, the author attempts to repair a particular cylindrical column by underwater concreting in accordance with the tremie method (Pham, 2007).

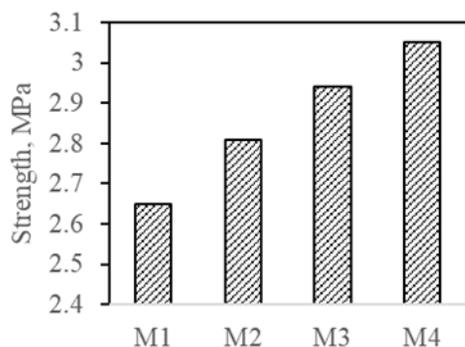


Figure 8. Flexural strength of AHPCs

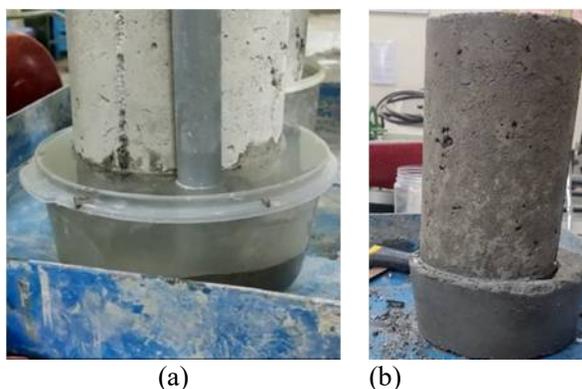


Figure 9. Illustration of the rehabilitation:  
(a) AHPC pouring into water; (b) specimen after rehabilitation by underwater concreting

To do so, the column is submerged into water, and the mixture M4 is pouring into the mould full of water, where the column is situated, as it can be seen in Figure 9(a). Thanks to the good quality of the M4, the repairing process has been done properly, as the column after the rehabilitation is shown in Figure 9(b). It is significant to note that the M4 forms a protective layer, which in turns shields the column from water and aggressive agents, as well as extend its life service (Nguyen, 2023).

### 4. Conclusion

Antiwash high performance concrete (AHPC) for rehabilitating the hydraulic structures submerged in water was studied in this paper. Four AHPC mixtures have been involved, in which superplasticizer dosages varied from 1% to 2% in conjunction with specialized anti-washout admixture. Besides, a particular AHPC mixture has been used for repairing the structure by underwater concreting.

The experimental results showed that at fresh state the higher superplasticizer dosage, the higher slump

flow of the AHPC mixtures i.e. the more workable mixture, and the higher mixture mass loss inside the water. Meanwhile, at hardened state the higher superplasticizer dosage, the higher compressive strength gains. The single AHPC, which achieved slump flow of 20 cm and strength class of 50MPa, was chosen for successfully rehabilitating the structure submerged in water by mean of tremie method.

Last but not least, the outcomes of this study are fruitful for the further study on load-carrying capacity of the structure after rehabilitation by underwater concreting.

### Acknowledgement

For the collaboration on the experimental study presented in the paper, the author would like to thank the students Nguyen Chien Thang, Ta Manh Cuong and Nguyen Thu Quynh at Thuyloi University. The support from Sika Vietnam Ltd. and VMAT companies for the material supply is also acknowledged.

### References

- EFNARC. 2002. *Specification & guidelines for self-compacting concrete*. English ed. Norfolk, UK: European Federation for Specialist Construction Chemicals and Concrete Systems.
- EFNARC. 2006. *Guidelines for Viscosity Modifying Admixtures for Concrete*. English ed. Norfolk, UK: European Federation for Specialist Construction Chemicals and Concrete Systems.
- Ngo, T.L. (2020). *Study on the implement of fine-grain concrete with glass fibre for rehabilitation of marine structure at Giao Thuy - Nam Dinh*, Master Thesis document, Thuyloi University.
- Nguyen, T.H. (2023). *Study on the antiwash fibre-reinforced concrete and repair of the structure*. Master Thesis document, Hai Phong University.
- Nguyen, V.D. & Vu Q.V. (2021). *Effect of additive compounds on concrete used for the construction of hydraulic structure*. Journal of water resources and environmental engineering No. 77.
- Neville A.M. (2002). *Concrete Properties 4<sup>th</sup> edition*. Person Education Limited, Edinburgh.
- Nguyen, V.D. (2022). *Research on concrete technology used for rehabilitating the structures by underwater concreting*. Scientific document report, Thuyloi University.
- Okamura, H. & Ouchi M. (2003). *Self-Compacting Concrete*. Journal of Advanced Concrete Technology, Vol. 1, No.1, p. 5-15.
- Pham, H.C. (2007). *Underwater construction techniques*, Publishing house of Transportation.
- Vu, Q.V. (2011). *Study on the proportion and properties of self-compacting concrete using manufactured sand*. Journal of water resources and environmental engineering No. 33.